Advanced Fuel Cycle Initiative (AFCI)

Semi-Annual Review

Systems Analysis

Repository Benefits

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Science in the National Interest

Outline

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Systems Analysis - Repository Benefit - Objectives

- ***Assess AFCI benefits for the U.S. geologic repository program.***
- ***Quantitative evaluation of repository issues:***
  - ***heat load and thermal management,***
  - ***mass and volume,***
  - ***radiotoxicity and dose,***
  - ***waste form optimization, etc.***
- ***Provide the technical basis for improvements in cost, capacity and performance for a repository***
- ***Provide the technical potential to defer the need for additional repositories.***
- ***Establish cooperation with DOE-OCRWM to establish mutual understanding of potential repository impacts***

Repository Benefit Products

- **Separations**
  - **Separation criteria/metrics tied to repository benefit**
- **Transmutation Systems Scenario Analysis**
  - **Input on metrics**
  - **Quantify potential for repository capacity increase**
- **ANL Study: Repository Benefit Analysis - Series I Impact**
  - **Evaluation of repository thermal limit improvements**
  - **Evaluation of repository performance improvements**
  - **Implications for repository capacity**
- **Cooperation with DOE-RW**
  - **MOA**
  - **Initial cost savings analysis**
  - **Potential for input to analysis of need for second repository**

Repository Benefit input to Separations Criteria

- **Primary repository benefits all depend on reductions in Pu, Np, Am.**
  - **Capacity (long-term thermal load), Performance (peak dose reduction), Long-term proliferation resistance**
- **Recommended separation efficiencies depend on recycle scenario**
  - **Series 1 with single or few Pu cycles have repository benefit limited by MOX fuel disposal, 90% separation adequate**
  - **Multi-recycle and Series 2 gain greater benefit to %99-99^{+} Pu and %95-99 actinide separation, cost/benefit needed**
- **Cs/Sr management offer benefits primarily to repository operation**
  - **With some actinide reduction, 90% Cs/Sr separation is beneficial**
  - **With multi-recycle/Series 2, 97-99% separation beneficial, cost/benefit needed**
- **Long-lived fission products bound YM-type repository performance for the U.S. regulatory compliance period**
  - **Current performance is sufficient**
  - **Separation/transmutation, while possible, does not appear to justify cost**
  - **Recommendation to dispose in an optimized, robust waste form**

Ongoing need for quantifiable metrics for evaluating system trade-offs.

Transmutation Systems Scenario Analysis

- **AFC deployment scenario evaluation -using accumulation of SNF, plutonium and actinides as a performance measure.**
  - **Continued use of nuclear energy at current capacity generates 4 YMP loads of SNF by 2100, maintaining current fractional contribution generates 7 YMP loads.**
  - **Commitment to AFC, second repository or massive indefinite storage will be needed early during deployment of new plants (2010-2020)**
  - **Based on long-term heat load limits, AFC deployment can defer need for additional repository capacity:**
    - **MOX recycle delays but does not greatly reduce thermal load**
    - **Multi-recycle can provide several-fold improvement**
  - **Only fast spectrum systems can actually reduce total inventories of plutonium and minor actinides**

Ongoing need for quantifiable metrics for evaluating system trade-offs.

"Repository Benefit Analysis - Series 1 Impact"

R. A. Wigeland, T. H. Bauer, T. H. Fanning, E. E. Morris
ANL-AFCI-089

- **Repository Thermal Analysis for AFCI Scenarios**
  - **ORIGEN2 used to calculate radionuclide evolution through fuel cycles and thermal output history in repository**
  - **CINDA/G used to build YM-like repository thermal model**
    - **Waste package surface, drift wall, midpoint between drifts tracked for comparison to design limits**
    - **Conduction, radiation, simulated drift cooling included**
    - **Comparable to results from complex YMP multi-scale models**
  - **Analyze AFCI Series 1 scenarios to determine thermal limits/benefits**
- **Repository Performance Analysis for AFCI Scenarios**
  - **Simplified version of GoldSim model (used for YMP Site Recommendation)**
  - **Define AFCI waste streams with proposed waste forms**
  - **Analyze AFCI Series 1 scenarios to determine qualitative repository performance impacts.**

Repository Thermal Analysis

ANL-AFCI-089

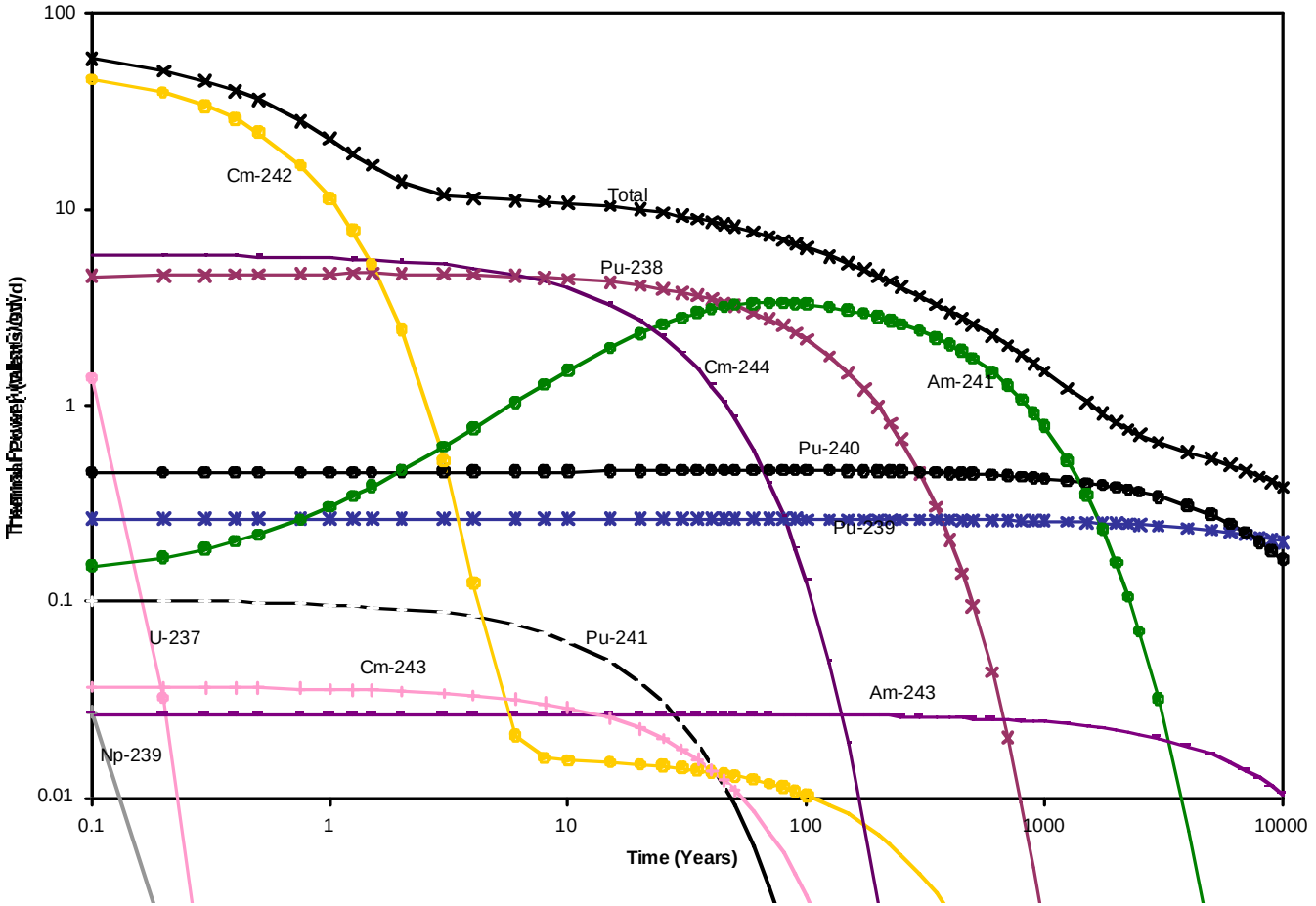

Figure 3: Normalized Thermal Power of Actinides and Daughters for the Extended-Burnup PWR Case (50 GWD/MT)

Repository Thermal Analysis

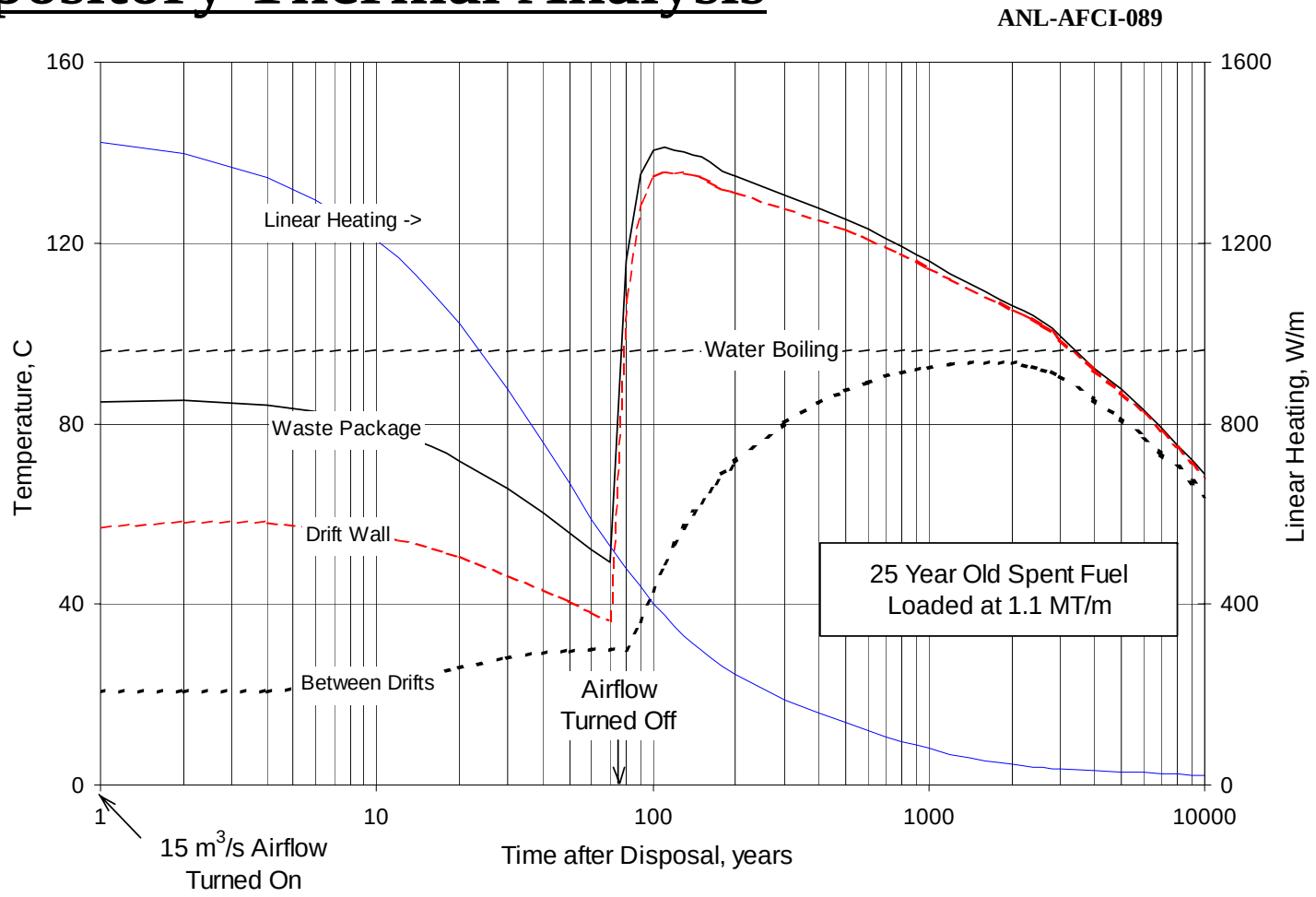

Fig. 5 Computed Repository Temperatures for Direct Disposal of 25 Year Old, 50 GWD/MT PWR Fuel

Repository Thermal Analysis

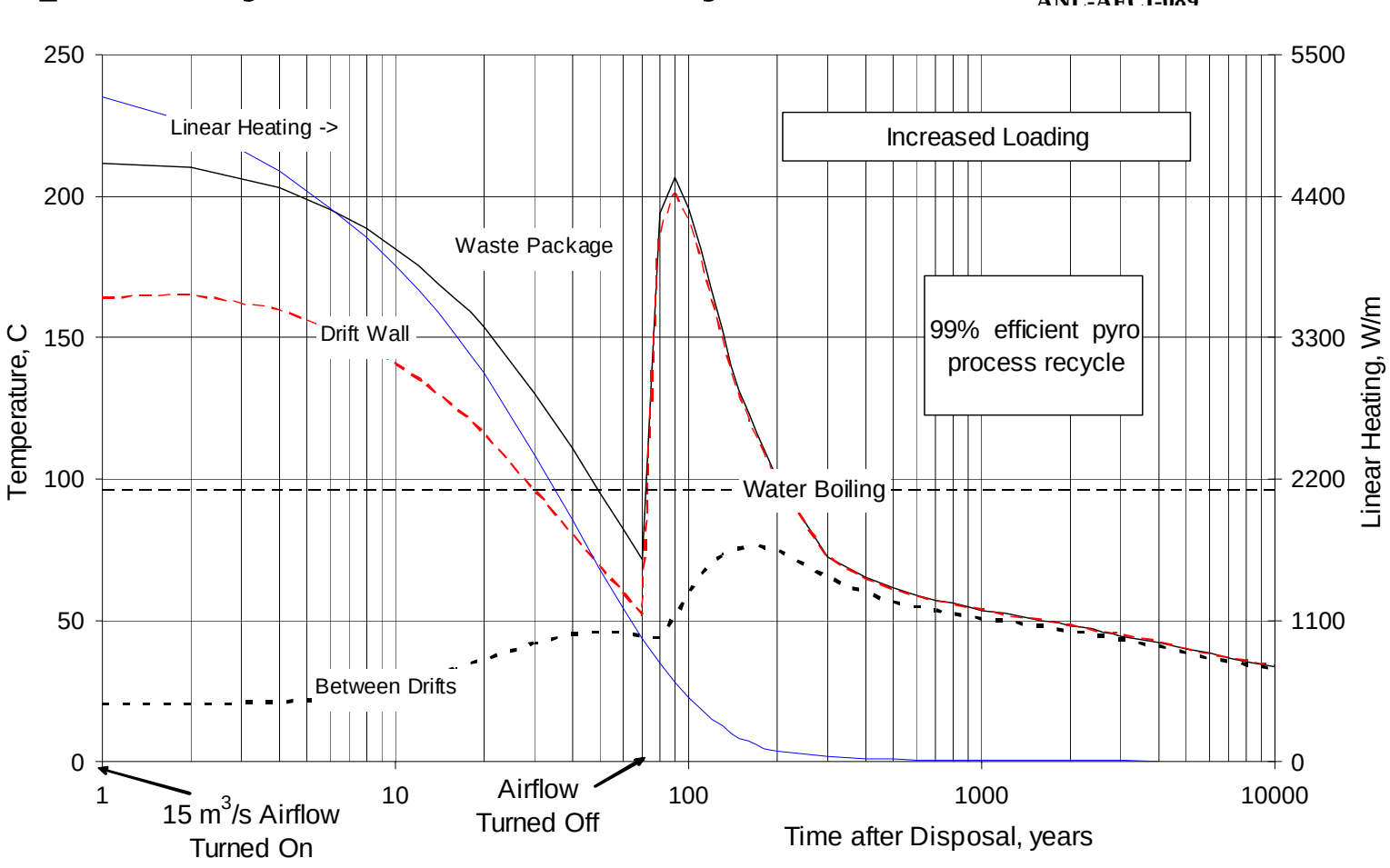

Fig. 8 Computed Repository Temperatures with Actinide Removal and Increased Loading Limited by Fission Product Heating.

Repository Thermal Analysis - Summary

- **Removal of Cs/Sr lowers operational period temperatures and permits a much shorter forced cooling period, but does not significantly impact linear mass loading limited by long-term limit to retain sub-boiling 'drainage zone' between drifts.**
- **Removal of actinides at %99 efficiency allows about 3X increase in linear mass-equivalent loading, limited by 200C drift temperatures following closure.**
- **Removal of both actinides and Cs/Sr permits linear mass-equivalent loading to increase by large factors (20X for 99% actinide removal).**

Table I. Repository Linear Loading Increase **ANL-AFCI-089**

Pu & Am Separation Efficiency	0%	90%	99%	99.9%
Loading Benefit	1.0	2.1	3.2	3.4
Loading Benefit w/FP Removal	~1.0	3.0	20	59

Repository Performance Analysis

- **Simplified performance assessment, with conservative assumptions regarding loss of cladding performance and use of waste form with performance similar to borosilicate glass.**
- **Once thru MOX, twice thru MOX and once thru Pu/Np all give maximum long-term dose rate within 30% of direct disposal.**
- **A CORAIL type scenario with multiple cycles Pu only or all transuranic recycle could result in significant (3X) reduction in long-term dose, unless the final cycle is disposed of in glass-like waste form.**
- **Better AFCI specific waste form models would improve future analyses.**

Development of Initial 'Repository Benefit' Metrics

- **There is no single, simple metric for benefit to geologic disposal from advance fuel cycles. Possible measures:**
  - **Volume, Mass, Near-term thermal, Long-term thermal, Short-term dose, Long-term dose, Radiotoxicity, Proliferation risk, Criticality...**
- **We are developing draft metrics for comparison between AFC scenarios and against direct disposal:**
  - **Interface to systems studies, Draw 'feedback'**
- **First component is long-term thermal load, from termination of ventilation through peak inter-drift temperature:**

  Integrated thermal output from 100 to 2000 years
- **Second component is near-term thermal load at termination of ventilation drives peak rock wall temperature:**

  Thermal output at 100 years

‘Repository Benefit’ Metrics

- **Gen-IV also developed metrics for “Waste Minimization”**
  - **Waste mass: MT/GWeYr compared to reference of 15-20 MT/GWeYr**
  - **Waste volume: m^3/GWeYr compared to reference of 15-20 m^3/GWeYr**
  - **Long-term decay heat: kW/GWeYr (500 yr out of core) compared to reference of 1-3 kW/GWeYr**
  - **Radiotoxicity: MSv/GWeYr (500 years out of core, activity times dose factor per ICRP72) compared to reference of 500-1500 MSv/GWeYr**
- **The Gen-IV metrics were heavily influenced by international input.**
- **Nobody was happy with them, but the direction of disagreement averaged to neutral!**
- **After much discussion, weighting factors ended up equal.**
- **Many other metrics were debated during 18 month process, with several deferred to future selection process.**

AFCI has the advantage of a more focused repository definition and more detailed analysis. Criteria and metrics are still a challenge.

AFCI-YMP Cooperation: MOA

- **A draft Memorandum of Agreement is in review between DOE-NE and DOE-RW for cooperation in evaluating "potential benefits to a geologic repository that could result from the successful development and application of advanced fuel cycle technologies."**
  - **Recognizes the mandate of each program:**
    - **RW has a focused mission and mandate to provide for the safe geologic disposal of spent nuclear fuel and high-level radioactive waste.**
    - **NE has a advanced fuel cycle program to develop advanced fuel treatment technologies.**
    - **Successful deployment of these technologies could result in significant changes in future waste streams destined for geologic disposal and thus, could impact many aspects of future repository design, operation, and performance.**
  - **Provides for exchange of baseline information, evaluation of potential waste stream changes from AFC deployment, development of framework for cost impacts.**

"Repository Baseline For Analysis of Interactions with the Advanced Fuel Cycle Initiative Program."

Pre-Decisional Study, HQ-ST-03-02C-001, Booz-Allen-Hamilton, June, 2003.

- **Provides YMP baseline information for perturbation analysis**
  - **Receipt rate, loading, statutory period performance assessment**
  - **Waste package cost: $400K/package**
  - **Drift cost: $2K/linear foot**
  - **Thermal Loading: 1.42 kW/meter (need technical basis)**
- **Expansion potential: 140,000^{+} Mt (need technical basis)**
- **Initial impacts based on YM perturbation (no design/operation changes) using available processing experience for assumptions:**
  - **La Hague, West Valley waste streams (need AFCI waste descriptions).**
  - **Assessed near-term impact for small fraction of YMP SNF stream.**
    - **Using these assumptions, cost saving is only $17K/MT**
  - **Not yet evaluating technical capacity limits beyond 83KT SNF, so impact on need for second repository not determined.**

We need to work together to develop the basis for evaluating the long-term AFC impact on geologic disposal.

Summary

- **Systems analyses of potential repository benefits from AFC scenarios have been conducted and coordinated with separations and transmutation system studies.**

- **With effective removal of actinides, AFC can significantly impact repository technical capacity measured against thermal design limits. Cs/Sr management becomes most valuable after significant actinide reduction.**

- **Analyses currently provide comparative benefits. Quantitative metrics are being developed against various geologic disposal parameters.**

- **Cooperation with DOE-RW is progressing and initial baseline information has been shared.**